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# Cordaitalean Leaf: A northern hemisphere taxon from Pench Valley Coalfield, Satpura Gondwana Basin, Madhya Pradesh, India

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## ABSTRACT

The occurrence of *Cordaites*, a Cordaitalean leaf of the Northern hemisphere from Satpura Gondwana Basin, Rawanwara Area of Pench Valley Coalfield, Parasia, Chhindwara District Madhya Pradesh, India, is exclusive. This study indicates that the contemporaneous floras (Angara, Cathaysian, and Euramerican floras) possess characteristic affiliation with Gondwana flora and *vis a vis*. This suggests there was a possibility of linkage, association, or presence of ancestry contemporary floras with Gondwana flora. This is the first report of *Cordaites* from the Satpura Gondwana Basin with cuticular features.

**Keywords:** *Cordaites,* Cuticle, Pench Valley Coalfield, Gondwana flora

## 1. INTRODUCTION

Cordaitean fossil leaf of northern hemisphere *Cordaites* Unger 1850 are well known from the Carboniferous and early Permian. It is well described in Euamerican flora. The *Cordaites* is an extinct gymnospermous group of plants with variable growth habits and palaeoecological tolerances. The *Cordaites* trees grow up to 5 meters tall with arenchymatous stilt roots, which few workers consider to be mangroves-like forms and thicket-forming, understory shrubs (Costanza 1985). Cordaites and Angaridium/Angaropteris represent the Angara flora in Russia, the Russian Federation, and the Far East.

Earlier workers considered that Gondwana *Neoggerathiopsis* is similar to the northern genus *Cordaites* in external morphology (Seward 1917; Seward and Sahni 1920; Meyen 1972; Maheshwari and Meyen 1975; Rigby et al. 1980). However, Pant and Verma (1964) and Maithy (1965) supported the retention of both genera. Globally, the leaves are considered to be different. Reports of leaves from Zaire (HØeg and Bose 1960), Argentina (Archangelsky et al. 1981), and India (Srivastava 1991) consider thin veins between thick veins as *Cordaites* which is different from *Neoggerathiopsis.* The report of *Cordaites* from



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India is from Karharbari and Barakar formations (Singh et al. 2007). Only one species of *Cordaites dumanii* is described from Duman Hill, Chirimiri Coalfield, India, from Karharbari Formation (Chandra and Srivastava 1991). The other Indian authors considered it at a generic level as *Cordaites* sp. without species. Srivastava (1992) evaluated the external morphological feature of *Cordaites* and *Noeggerathiopsis* to be distinguishable as *Cordaites* have thick and thin veins whereas, *Noeggerathiopsis* have uniform veins.

The present work focuses on the *Cordaites* leaves, reported from the Rawanwara area of Pench Valley Coalfield, Parasia, Chhindwara District, Madhya Pradesh, India. This leaf is considered to be an alien leaf from the northern hemisphere. It is considered that there was a uniformity of Carboniferous flora in the southern and northern hemispheres. After the onset of glaciation, the Glossopteris flora was occupied by the Southern hemisphere (Gondwanaland). Euroamerican flora included Lepidodendrids, Calamites, Sphenophylls and pteridosperms dominated in (the North America and Europe) northern hemisphere. Meanwhile, Cathaysian flora (Gigantopteris flora) flourished in China and extended south of Sumatra. The Angara Flora consisted of *Cordaites* and Pteridosperm around the Siberian region and northwest China. Chaloner and Lacey (1973) considered North American flora as the fifth flora based on the characteristic genera of each province. *Cordaites* are reported from Euroamerican flora, Cathaysian flora, Angara Flora and North American flora.

In India (Glossopteris flora), there are many reports of Cordaitalean leaves of *Noeggerathiopsis* from Permian, but scanty reports of *Cordaites* leaves. The presence of both the leaves from the Gondwana basin suggests that two types of Cordaitalean leaf forms co-existed in the Gondwana flora. There is only one report of Cordaites leaves from Satpura Gondwana Basin based on morphology (Pillai 2011). However, it was not described in detail. This is the first report of *Cordaites* from the Satpura Gondwana Basin, which provides detailed morphological and cuticular characteristics.

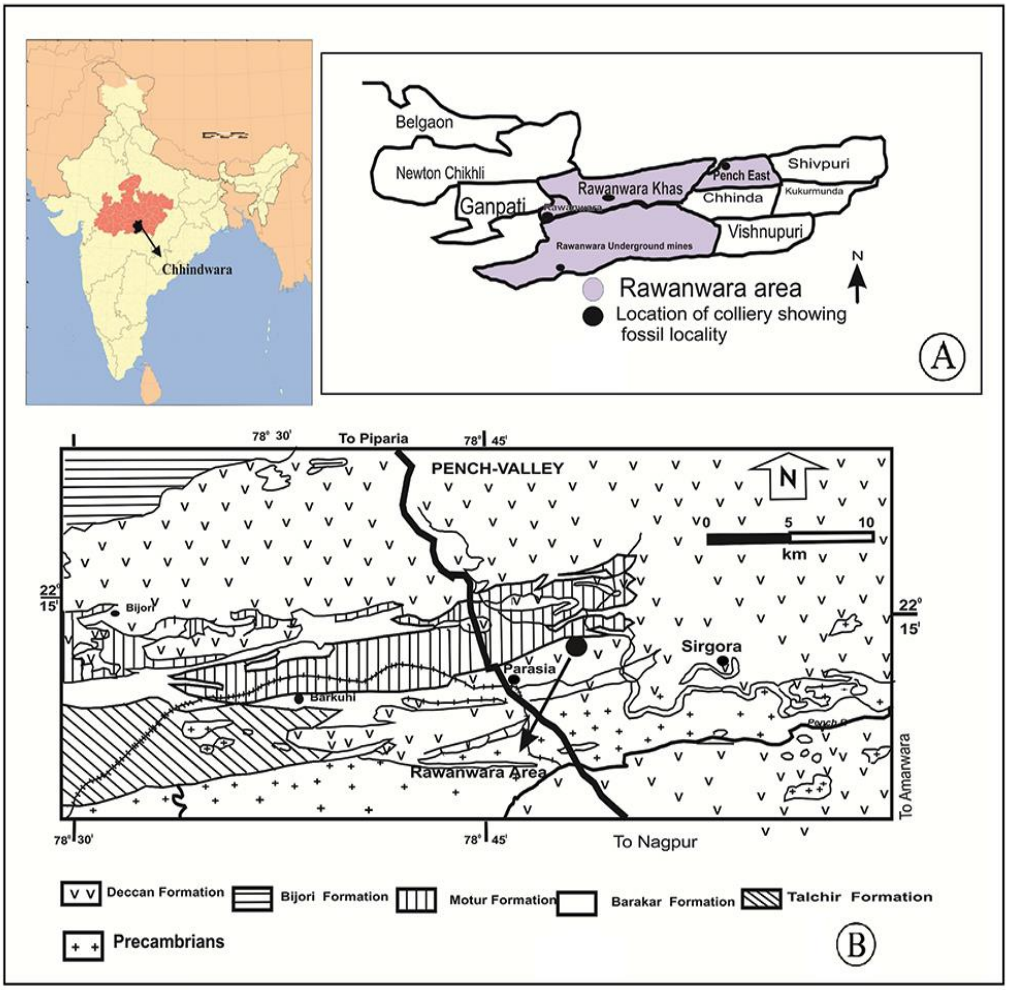


**Fig. 1** (A) Sketch map showing position of different collieries in the Rawanwara area; (B) Geological map showing the location of Pench Valley Coalfield, Satpura Gondwana Basin



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**General geology**

Satpura Gondwana Basin is the westernmost basin of Peninsular India and is situated between 22° 06' and 22° 28' latitude and 77° 48' and 78°53' longitude and covers an area of 12,000 sq. km. The thickness of Gondwana sediments is estimated to be more than 500m in the Satpura Basin. Deccan trap stretches the area in the east and west. Lower Gondwana outcrops are distributed mainly in the southern part of the basin and progressively younger units outcrop towards the north. The area is drained by three Rivers, the Pench, Kanhan, and Tawa, which facilitate the demarcation of the field into three groups (Fig. 1A). Satpura Gondwana Basin is divided into seven areas by Raja Rao (1982). Quseley (1835) was the first to notice the presence of coal in Satpura. Medlicott (1873 and 1879) conducted a thorough geological survey, focusing mainly on the Pench-Kanhan coalfields.

Satpura Gondwana Basin is divided into three units: lower, middle and upper. The lower unit consists of Talchir, Barakar, Motur, and Bijori Formations. The middle unit comprises Pachmarhi and Denwa formations, while the upper unit is represented by Jabalpur Formation and Inter - trappean sediments. Deccan traps cover the area in the east and west. Motur and Bijori Formations are known only in this area. They are correlated with Barren Measures and Raniganj Formation, whereas the relationship between Pachmarhi and Bijori is still not well documented. The thickest unit in the basin is the Bijori Formation (1590m). The discussed stratigraphic succession of the Satpura Gondwana Basin is proposed by Raja Rao (1982) and presented in Table 1.

**Table 1** Stratigraphic nomenclature of Satpura Gondwana Basin (after Raja Rao 1982)

| Age | Formation | Lithology (Thickness) |
|---|---|---|
| Recent | Alluvium | |
| Upper Cretaceous to Eocene | Deccan Traps basic flows dykes and sills | Basalt |
| Upper Cretaceous | Lameta | Conglomerate, limestones and clays. |
| Lower Cretaceous | Jabalpur | Massive sandstones with jasper conglomerates, white clays red clays, carbonaceous shale and coal lenses (50 to 100m) |
| Rhaetic | Bagra | Predominantly coarse conglomerates with bands of calcareous sandstones, variegated clays limestones and dolomite (180 to 240 m) |
| Upper part of Lower Triassic to Middle Triassic | Denwa | Soft variegated clays interbedded with sandstone bands, conglomeratic at places (about 350m) |
| Lower Triassic | Pachmarhi | White-coarse grained cross bedded sandstone with lenses of sub angular quartz pebbles (about 750m) |
| Upper Permian | Bijori | Micaceous flaggy sandstones with shales at places micaceous (180-250m) |
| Lower Permian | Motur<br>Barakar | Buff green and variegated clays with coarse to very coarse grained sandstone (about 400m)<br>Coarse to medium grained sandstones, shales, carbonaceous shales and coal seams (250m-400m) |
| Upper Carboniferous (?) | Talchir | Diamictites sandstones, grey and olive green needle shales, varves and rhythmites (about 490m) |
| Precambrian | | Gneiss, schists, quartzites, limestone etc. |

**Barakar Formation**

The Barakar Formation overlies the Talchir Formation. Barakar constitutes the only coal-bearing formation in the region. Barakar exhibits conformable relations with the underlying Talchir rock and its relationship with the overlying Motur seems to be marked with slight unconformity in the Pench Valley region. The total thickness of Barakar developed in the Pench area has been estimated to be about 120m-160m by Medlicott (1873). Their exposure covers hardly 15% of the exposed Gondwana terrain in the region.



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It comprises shale, carbonaceous shales, and sandstone grading from fine to coarse-grained shale and shaley sandstone, siltstone, shaley coal, and coal. The shales are grayish and, in some places, occasionally grade into carbonaceous shales. The Barakar Formation contains three interbedded economically workable coal seams. Fossils of typical age are common in the shales. The Barakar Formation is encountered in the Mohapani – Gotitoria area in the northern periphery of the Satpura Basin. Further to the south, the thick pile of Supra-Barakar sediments forms a massive blanket over the coal measure. The Barakar sediments show wide lateral variation in thickness in the Satpura Basin. The formation attains a maximum thickness of 450m at the Pathakhera Coalfield in the middle part of the basin belt. Progressive reduction in the thickness has been recorded both to the east and west Pathakhera part of Satpura Valley. The Barakar / Talchir contact in the area is faulted.

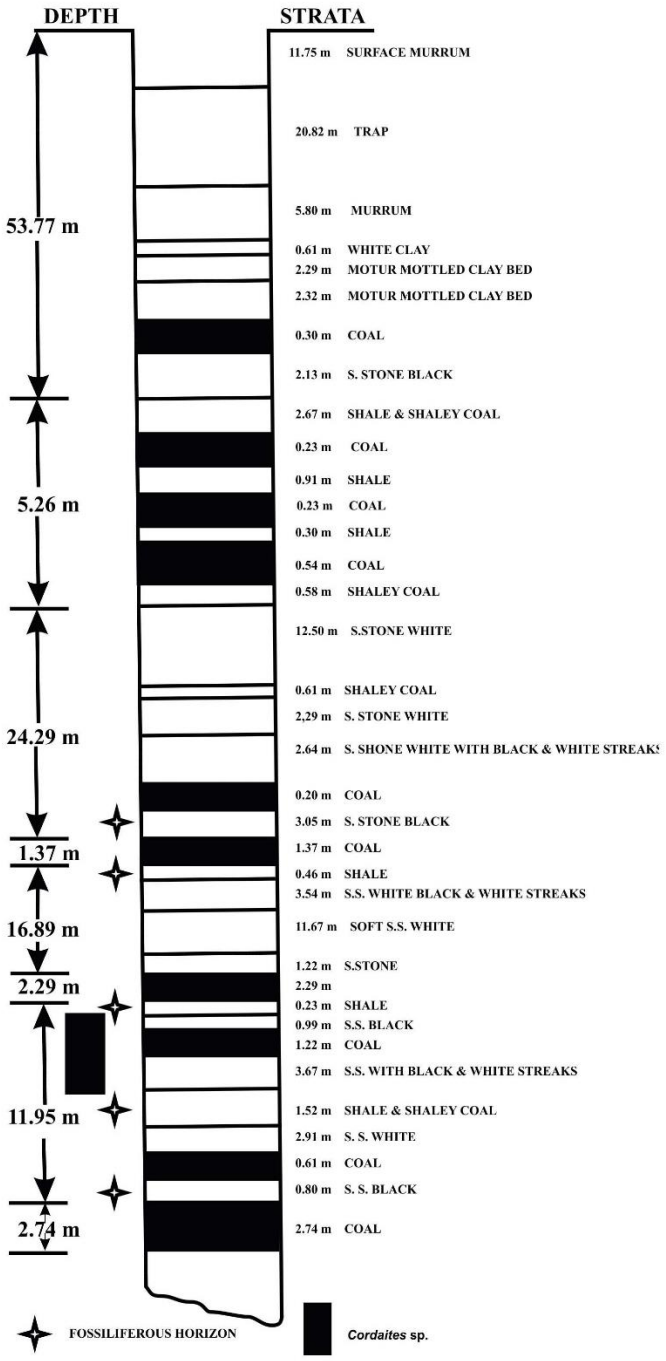


**Fig. 2** Geological section of Rawnwara area, Pench Valley Coalfield

## 2. MATERIALS AND METHODS

**Megafossils**

The study of plant fossil assemblages from the Rawanwara Area of Pench Valley Coalfield, Satpura Gondwana Basin, has been undertaken. This Coalfield is an important coal-producing area of Satpura Gondwana Basin, Madhya Pradesh. The geology and coal resources of the Coalfield are well known. Currently, coal is mined by Western Coalfields Limited, Nagpur and for Coal exploration, the Coalfield is divided into several areas.

Rawanwara Area of Pench Valley Coalfield, Satpura Gondwana Basin is located in the north-east of Parasia Township, Chhindwara District, Madhya Pradesh (Fig. 1B). This is situated 3 km west of Sirgora on the west bank of the Pench River and lies at about 78º 50' N and 22º 10' E. The fossiliferous horizon belongs to Lower Barakar Formation.

The Coal seams belong to Barakar Formation and are numbered from I to V (from top to bottom). Plant fossils belong to lower coal seams viz., seam no. IV and V. The location of fossiliferous beds and lithostratigraphic succession of the area are shown in Fig. 2.

The fossils are preserved as carbonaceous shale exposed overlying and underlying the coal seams. Plant fossils are mostly preserved as impressions. Samples often show a thin film of carbon, but on the chemical treatment, they become brittle and it is challenging to get cuticular pieces. The specimens are well preserved and show the details of external morphological features that help identify plant fossils. Plant fossil specimens were examined under Low Power Binocular (Wild Heerbrugg 1X) incident light. Exterior morphological features, e.g., shape, apex, base, nature of midrib, and details of venation pattern were studied after cleaning the specimen with the help of a chisel and hammer. Fossil leaves were described under standard taxonomic terms and patterns (Dilcher 1974; Chandra and Surange 1979).

**Cuticles**

The cuticles were prepared by cellulose acetate pulls in concentrated nitric acid for a few days. To increase the rate of reaction, a small amount of potassium chlorate ($KClO_3$) was added. Cuticles were repeatedly cleaned in water to neutralize the acid when they changed from black to brown. The cuticles were treated with 5% potassium hydroxide (KOH). The lower and the upper epidermis were separated by differential maceration in concentric Nitric acid ($HNO_3$) and KOH solutions. The cuticles were repeatedly washed in water and then kept in a hydrogen peroxide ($H_2O_2$) solution overnight. The cuticles were cleaned several times, stained in saffranine, dried in polyvinyl alcohol and mounted with Canada balsam. Under a high-power microscope (Olympus Vanox AHBS3), the cuticles were photographed in transmitted light and the structural characteristics were studied.

## 3. SYSTEMATIC PALAEOBOTANY

Division: Gymnospermophyta ('seed plants')
Class: Pinopsida
Order: Cordaitanthales ('Cordaites') Meyen 1984
Genus: *Cordaites* Unger 1850
Type species: *Cordaites borassifolius* (Sternberg) Unger 1850

***Cordaites* sp.**

Locality: Pench East Incline underground project, Pench Valley Coalfield Satpura Gondwana Basin, Madhya Pradesh, India.
Horizon and age: Lower Barakar Formation, Lower Gondwana (Lower Permian).

**Description**

The present specimen is an incomplete leaf (Fig. 3.1) compression showing a thick texture, where the apex and base are not preserved. The leaf shows a wavy and folding structure on the surface. The feature is quite likely developed during the preservation of the leaf. The folding is much more evident in the central region of the leaf. The leaf is spathulate in shape, 18.1 cm long and 7.7 cm broad at its widest, asymmetrical in nature, margin entire and midrib absent. The leaf possesses parallel and forked veins and distinct thick and thin veins. Thin veins are 2-4 in number and present between two thick veins. Median veins are straight, whereas side veins are arched. The size of thick veins is 1-1.5mm. The thick veins on the right side of the leaf show grooved nature. Thin veins are blurred near the lower portion, but towards the upper part, they are very distinct. The vein density at the lower part of the leaf is three thick veins and twelve thin veins per cm. Vein density in the lower-middle and upper portions is two thick veins and twelve thin veins per cm.



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**Cuticle**

The adaxial surface of the leaf shows alternate light and dark bands of cells. The adaxial has cuticles (upper), which are non-stomatiferous bands that show darker bands than the costal bands which are light or more or less transparent cells. The darker intercostal band on the adaxial surface has cells with few stomata. The cells of the adaxial cuticle have a thin layer of cutin. The costal and intercostal cells are tetragonal in size and oblong in shape. Anticlinal walls are bent in nature. The cells have rounded corners parallel to the veins. The stomata have pair of sunken elliptical guard cells with two subsidiary cells and two lateral subsidiary cells. The stomatal density is very low.

**Comparison**

The present leaf has a spathulate shape with parallel running thick and thin veins resembling the leaf of *Cordaites* Unger 1850. The current leaf resembles the leaf described by Srivastava (1992, Pl. 4) as *Cordaites* from the Lower Barakar flora of Raniganj Coalfield. The size of the leaf (12.5 cm long and 5.5 cm broad), entire margin, thick and thin veins, and un-forked simple ribs emerging from the base are comparable. The specimen's cuticles also exhibit trichomes (Fig. 3.2), stomata with subsidiary cells (Figs 3.3-3.4), and thick and thin veins (Figs 3.5-3.6). The cuticular characteristic is similar to those of *Cordaites borassifolious* described by Šimunek et al. 2009.

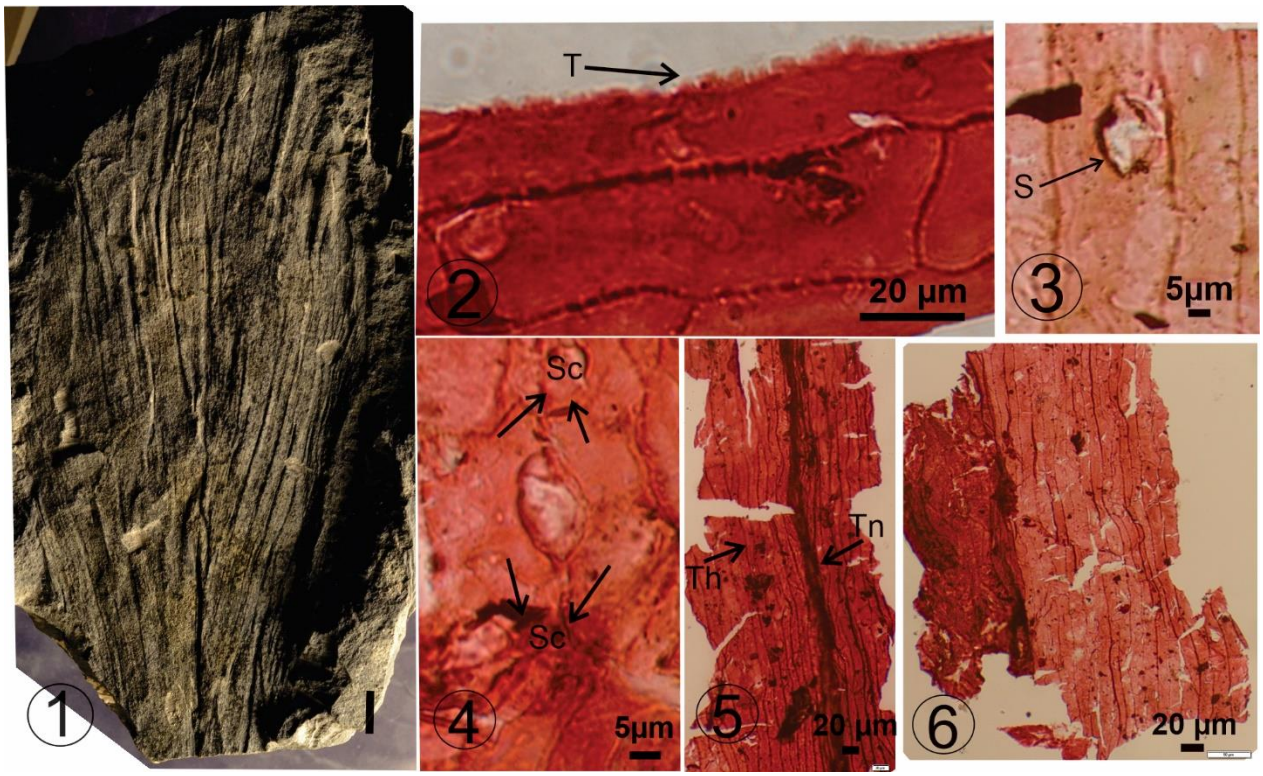


**Fig. 3** 3.1 *Cordaites* leaf showing thick and thin veins (Scale bar is 10mm); 3.2 Adxial epidermis of *Cordaites* with cuticles having with longitudinally oriented cells trichomes on the surface (T-Trichomes); 3.3-3.4 Adxial epidermis of *Cordaites* with stomatal opening and subsidiary cells (S-Stomata) (Sc-Subsidiary cells); 3.5-3.6 Cuticles showing thick and thin veins (Th-Thick veins, Tn-Thin veins)

## 4. RESULTS AND DISCUSSION

The genus *Cordaites* is typical flora of Northern Hemispheric genera, e.g., Euamerican, Angara, Cathysian. Recently, such leaves have been recorded from Lower Gondwana beds of India. Chandra and Srivastava (1991) described *Cordaites dumanii;* Srivastava (1992) and Singh et al. (2007) have reported *Cordaites* sp. from South Rewa Gondwana Basin, Raniganj, and Ib-River coalfields of Lower Gondwana beds of India. The *Cordaites dumanii* (Chandra and Srivastava 1991) described is from 6-7 cm in length and 1.2-2.8 cm in breadth in the broadest region. The leaves are spathulate to linear-lanceolate in shape. They show acute to an obtuse apex and their base is narrowly contracted. 6-8 thick veins emerge from the base, dichotomise 3-4 times, spread gradually, and run parallel without anastomosing. In between stouter veins or ribs, 2-4 finer veins are also running in the same direction. The density of finer veins is 15-20 per cm. It is smaller than the present *Cordaites* described. *Codaites* sp., described by Singh et al. (2007, Pl. 3, Fig. 4), is



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small compared to the current leaf, but the characteristic feature is unforked veins, thick and thin parallel veins are comparable with the present leaf. Seward and Sahni (1920) described *Cordaites* (*Noeggerathiopsis*) *stoliszkana* (Pl. 2, Fig.11) and *Cordaites* (*Noeggerathiopsis*) *hislopii* (Pl.1, Figs 8-10) from Karharbari Formation of Giridih Coalfield, later it was found that they belong to *N. hislopii* (Srivastava 1991). Pant and Verma (1964) described cuticular details of *Cordaites* and found them distinct from the cuticles of *N. hislopii.* Corditales are essential components of late Palaeozoic flora, but their existence in Southern Hemisphere is debatable due to the absence of reproductive structure. External morphological characters are considered for the identification of *Cordaites.* While *Cordaites* have relatively thick veins and thin parallel interstitial fibers between the veins, *Noeggerathiopsis* leaves have simple veins of uniform thickness across the lamina. Many workers have supported the distinction between *Noeggerathiopsis* and *Cordaites* (Maithy 1965; Chandra and Srivastava 1991; Srivastava 1992). The present leaf shows similarity with *Noeggerathiopsis* (parallel venation), but the presence of alternating thick and thinner veins distinguishes them and resembles the leaf of the northern hemisphere (*Cordaites*) (Stopes 1903; Reed and Sandoe 1951; Harms and Leisman 1961; Pant and Verma 1964). The morphological features of the present leaf is comparable with the *Cordaites*, i.e., leaf with thick and thin veins (Srivastava 1992) and the cuticular features are similar to *Cordaites borassifolius* leaf described from Radnice Basin (Late Palaeozoic continental basin) in Czech Republic (Šimunek et al. 2009). Apart from that, we retrieved only one specimen in the collection. Hence, *Cordaites* sp. is considered for specimen identification in the present work.

Many workers considered the presence of mixed floras at the Tethyan margin explained by the Palaeo-geographical model (Krassilov 2000; Berthelin et al. 2006; Hamad et al. 2008). Fluteau et al. (2001) model considered that the Late Permian flora of the Tethyan region before reaching the Arabian Peninsula, the Cathaysian flora mixed with Gondwana elements during the passage to Kashmir. Hence, we can observe that Glossopteris flora has Cathaysian flora and mixed flora. The second thought for mixed flora is climatic conditions that prevailed during the Upper Carboniferous in the northern hemisphere when most of the cordaitalean taxon and equisetalean forms flourished and such forms were present during Permian also but did not flourish because of the glaciation but when there was an alteration of climate the flora flourished successfully. The so-called mixed floral elements of the northern and southern floras likely have a common ancestor or affinity with Carboniferous floras. They were deceived by the harsh climatic circumstances during the early Permian, but they recovered during the late Permian when the climate became more conducive for their development. This is the first detailed description of *Cordaites* sp. with cuticular details from the lower Barakar Formation of the Satpura Gondwana Basin and indicates the presence of northern flora taxon mixing with Glossopteris flora.

## 5. CONCLUSION

The *Cordaites* leaf is considered as a member of the Euroamerican, Cathaysian, Angaran and North American floras (Srivastava, 1992). There are very few reports of *Cordaites* from the Indian Gondwana basins during the Permian. Hence, it is concluded that few taxa other than Glossopterids in the Gondwana flora have similarities with the northern flora, showing their lineage. Therefore, considering the present work, we conclude that there was an intermixing of flora during the Permian.

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**Author contribution**

Field work and preliminary analysis – SP; Manuscript preparation - SP, MS and AC wrote and finalized the manuscript.

**Ethical approval**

*Cordaites*, a Cordaitalean leaf from Northern hemisphere from Satpura Gondwana Basin, Rawanwara Area of Pench Valley Coalfield, Parasia, Chhindwara District Madhya Pradesh, India was observed in the work. The ethical guidelines for fossil & fossil materials are followed in the study for sample collection & identification.

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**Conflicts of interests**

The authors declare that there are no conflicts of interests.

**Data and materials availability**

All data associated with this study are present in the paper.

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